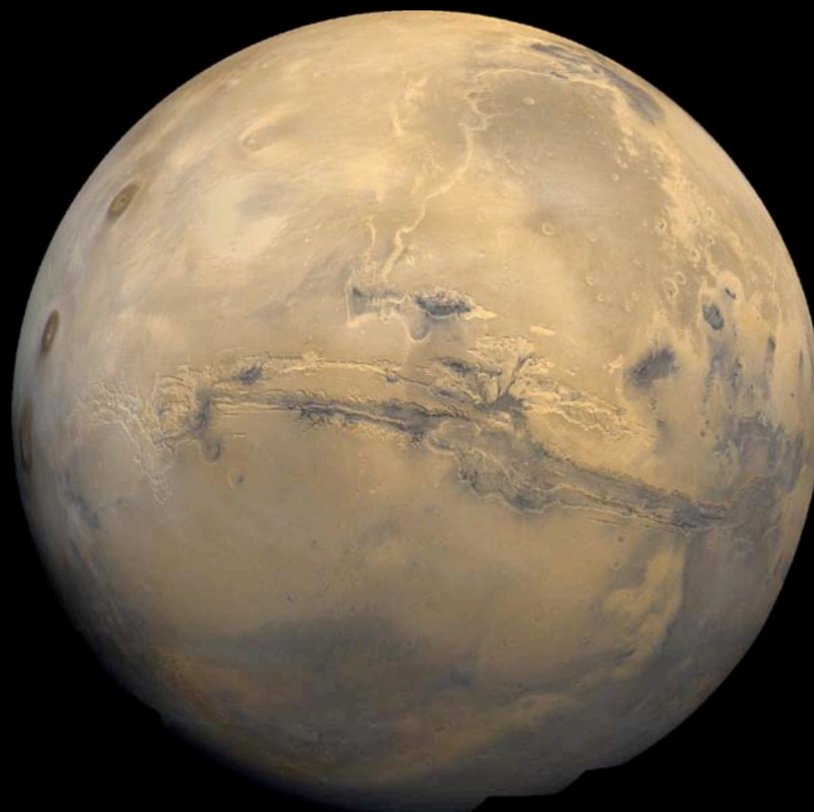
The Upside/Downside of Faster, Better, Cheaper

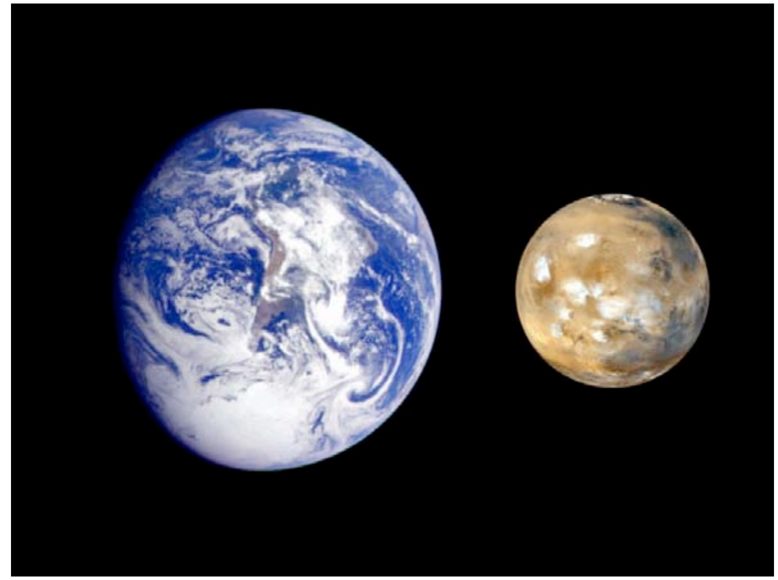


Dr. Steve Jolly
Lockheed Martin Space Systems

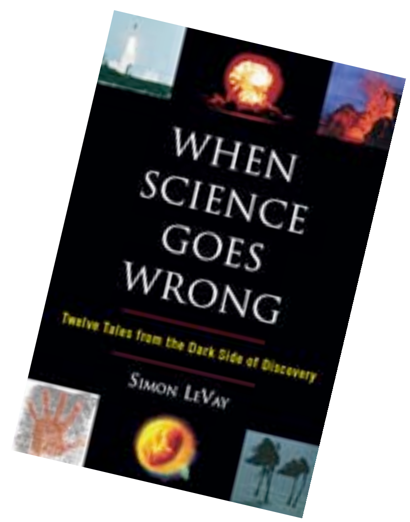
Image Credit: NASA/JPL/Malin
Space Science Systems

Historical (Hysterical?) Mars Missions

1. [Unnamed], USSR, 10/10/60, Mars flyby, did not reach Earth orbit
2. [Unnamed], USSR, 10/14/60, Mars flyby, did not reach Earth orbit
3. [Unnamed], USSR, 10/24/62, Mars flyby, achieved Earth orbit only
4. Mars 1, USSR, 11/1/62, Mars flyby, radio failed
5. [Unnamed], USSR, 11/4/62, Mars flyby, achieved Earth orbit only
6. Mariner 3, U.S., 11/5/64, Mars flyby, shroud failed to jettison
7. Mariner 4, U.S. 11/28/64, first successful Mars flyby 7/14/65
8. Zond 2, USSR, 11/30/64, Mars flyby, passed Mars radio failed, no data
9. Mariner 6, U.S., 2/24/69, Mars flyby 7/31/69, returned 75 photos
10. Mariner 7, U.S., 3/27/69, Mars flyby 8/5/69, returned 126 photos
11. Mariner 8, U.S., 5/8/71, Mars orbiter, failed during launch
12. Kosmos 419, USSR, 5/10/71, Mars lander, achieved Earth orbit only
13. Mars 2, USSR, 5/19/71, Mars orbiter/lander arrived 11/27/71, no useful data
14. Mars 3, USSR, 5/28/71, Mars orbiter/lander, arrived 12/3/71
15. Mariner 9, U.S., 5/30/71, Mars orbiter, in orbit 11/13/71 to 10/27/72
16. Mars 4, USSR, 7/21/73, failed Mars orbiter, flew past Mars 2/10/74
17. Mars 5, USSR, 7/25/73, Mars orbiter, arrived 2/12/74, lasted a few days
18. Mars 6, USSR, 8/5/73, Mars orbiter/lander, arrived 3/12/74, little data
19. Mars 7, USSR, 8/9/73, Mars orbiter/lander, arrived 3/9/74, little data
20. Viking 1, U.S., 8/20/75, orbiter/lander, orbit 6/19/76-1980, lander 7/20/76-1982
21. Viking 2, U.S., 9/9/75, orbiter/lander, orbit 8/7/76-1987, lander 9/3/76-1980
22. Phobos 1, USSR, 7/7/88, Mars/Phobos orbiter/lander, lost 8/89 en route
23. Phobos 2, USSR, 7/12/88, Mars/Phobos orbiter/lander, lost 3/89 near Phobos
24. Mars Observer, U.S., 9/25/92, lost just before Mars arrival 8/21/93
25. Mars Global Surveyor, U.S., 11/7/96, Mars orbiter, arrived 9/12/97
26. Mars 96, Russia, 11/16/96, orbiter and landers, launch vehicle failed
27. Mars Pathfinder, U.S., 12/4/96
28. Nozomi (Planet-B), Japan, 7/4/98, Mars orbiter, failed to capture
29. Mars Climate Orbiter, U.S., 12/11/98, lost upon arrival 9/23/99
30. Mars Polar Lander, U.S., 1/3/99
31. Deep Space 2, Probes, U.S., 1/3/99
32. 2001 Odyssey, U.S., Mars Orbiter, launched 4/7/01
33. Mars Express, ESA, Mars Orbiter, launched 6/03
34. Beagle 2, ESA, Mars Lander, launched 6/03, no contact since EDL
35. Spirit, U.S., Mars Rover, launched 6/10/03
36. Opportunity, U.S., Mars Rover, launched 7/7/03
37. Mars Reconnaissance Orbiter, U.S., Mars Orbiter, Launched 8/12
38. Phoenix, U.S., Mars Lander, Launched 2007

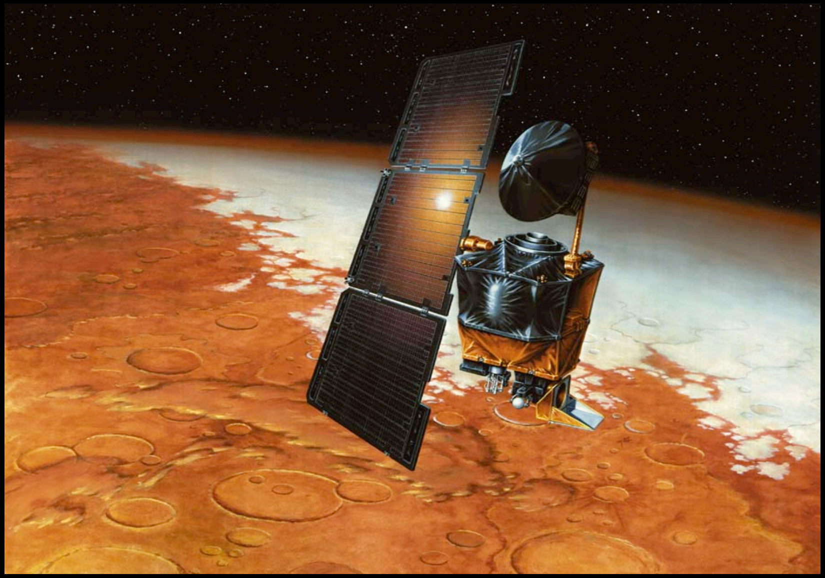


37% success rate …



Mars Surveyor '98 Project "Characteristics"

- "Faster, Better, Cheaper"
- Eliminate all non-value added activities
- Small Project Office management team
- Risk OK, but manage carefully
- Single string operation for critical operations where on line redundancy would require significant complexity
- Maximize commonality in hardware and software between vehicles
- No NASA budget increases
- Minimal IV&V
- Heavy dependence on heritage hardware and operations



The Failures

- **Mars Climate Orbiter**

  The mission loss was precipitated by an error in the (ground) software program that generated the Angular Momentum Desaturation files. …the files containing the magnitudes of the small forces impulses applied to the spacecraft had been delivered in English units (pounds-force seconds) instead of metric units (Newton-seconds).

- **Mars Polar Lander**

  The probable cause of the loss of MPL has been traced to premature shutdown of the descent engines, resulting from a vulnerability of the (flight) software to transient signals.

- **Systems Engineering Criticisms**

  In Some Cases Failed In Executing What Were Good Processes

  Risk Management Was Too Informal

  Risk Accumulated Incrementally Resulting in a Riskier Mission Than We All Recognized (MPL)

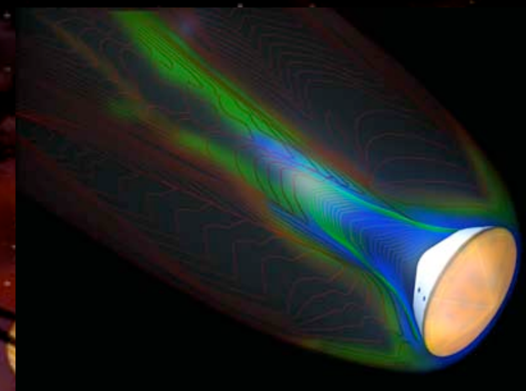
Looking Back: The Lessons (2002)

- Project significantly under funded for low risk (30% min)
- Needed more independent technical review and IV&V
- Needed more rigorous application of Mission Success principles
  - 2 page procedure then, 14 page checklist now
  - "Test like you fly", elimination of single person error opportunities are most important elements
- Keep track of "near misses" – an indicator of project health
- Very fine line between success and failure in these one-of-a-kind cost constrained programs

- So we have had 6 more years to reflect on FBC and the Mars 98 failures

- And several missions have been conceived and flown since then – including the “clean sheet” MRO and the resurrected Mars 01 Lander, now Phoenix

- Here are 10 topics (controversial?) that we all have stories about …

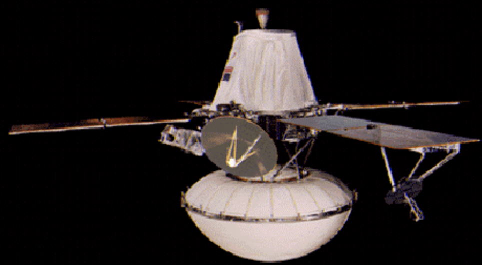


1. $ in perspective

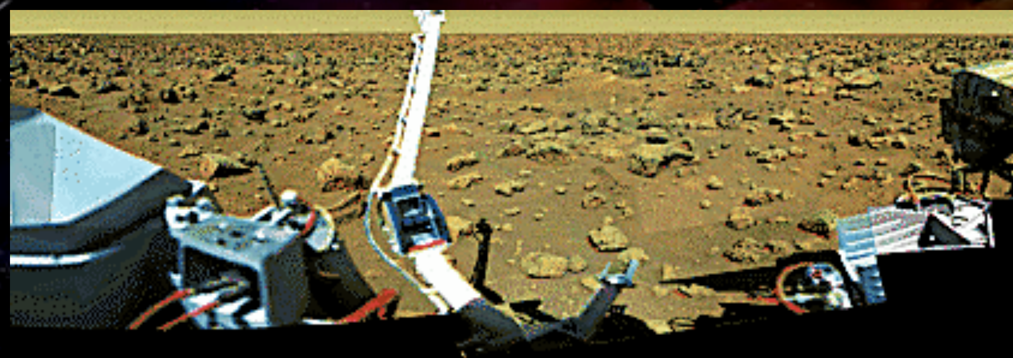
Image Credits: NASA/JPL/Lockheed Martin

2. Must become masters of the technology of <u>our</u> day

Orion Crew Module Physical and Functional Interfaces	Structures	Thermal Protection System	Passive Thermal Control	Mechanisms	Propulsion	Power	Command & Data Handling	Communication & Telemetry	Crew Interface	**Software**	Guidance, Nav. and Control	ECLSS	Crew Systems	Recovery & Landing System	Active Thermal Control
Structures															
Thermal Protection System															
Passive Thermal Control															
Mechanisms										1					
Propulsion										2					
Power										3					
Command & Data Handling										4					
Communication & Telemetry										5					
Crew Interface										6					
Software											7	8	9	10	11
Guidnace, Nav. and Control															
ECLSS															
Crew Systems															
Recovery & Landing System															
Active Thermal Control															



3. Lost the recipe from Viking?



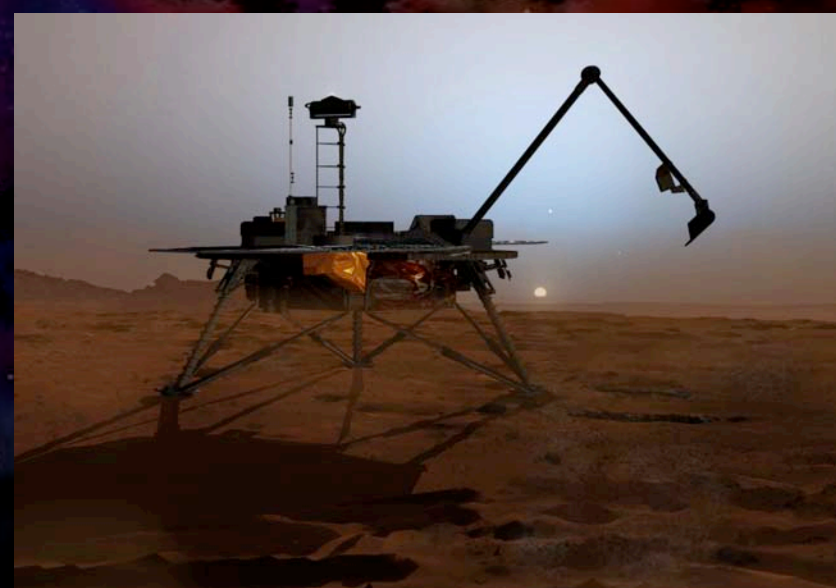
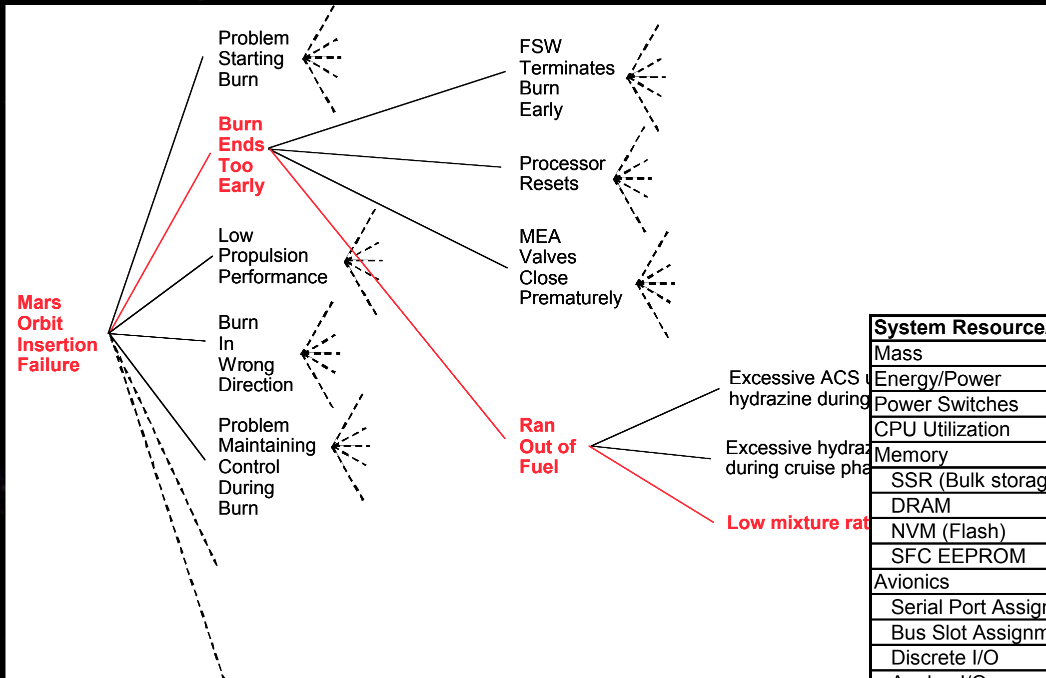
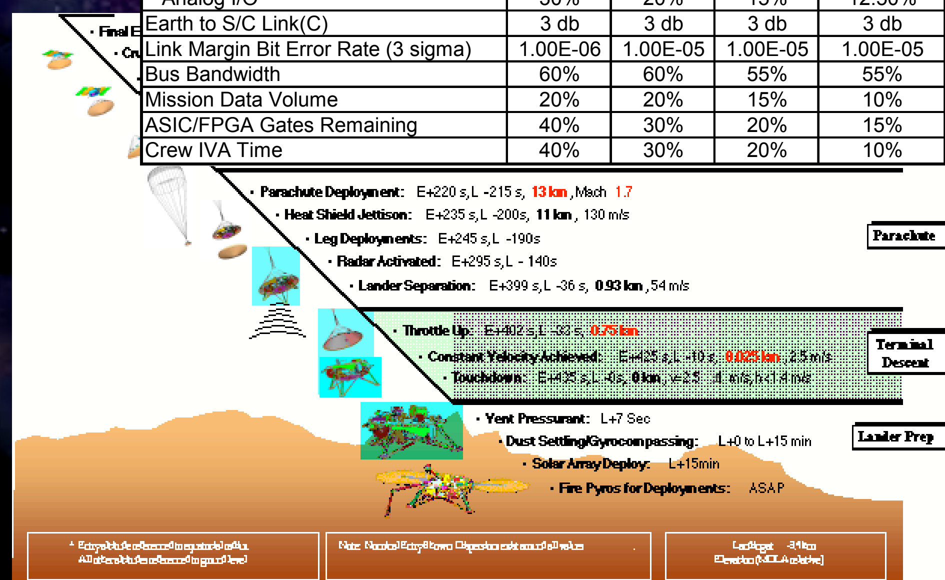


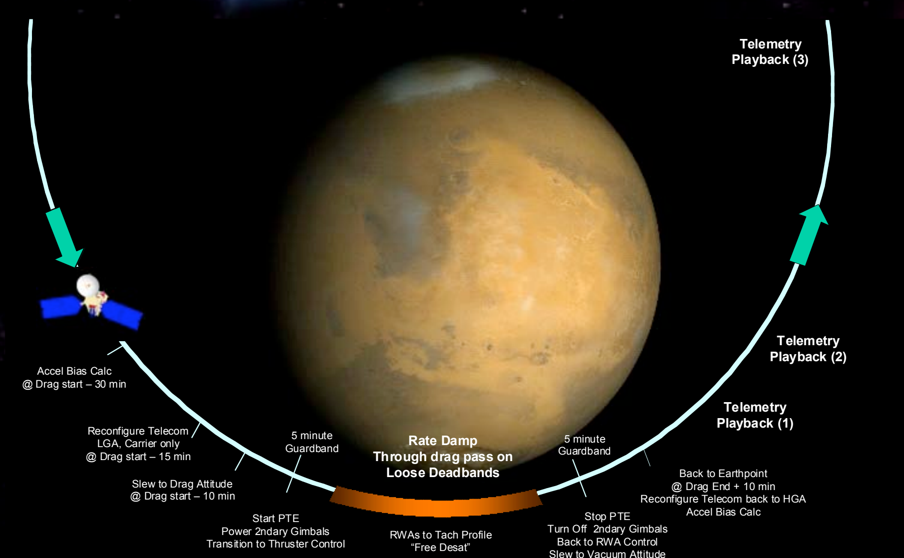
Image Credits:NASA/JPL

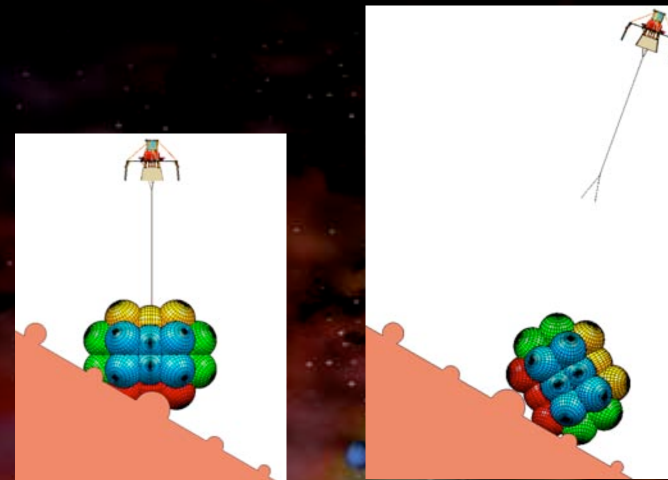


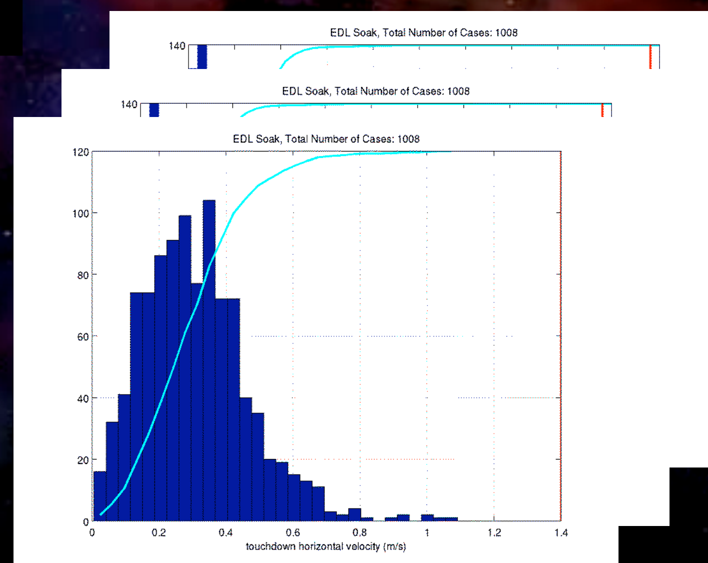
System Resource/Mission Phase	SDR	PDR	CDR	ATLO start	Launch
Mass	25%	20%	15%	10%	3%
Energy/Power	30%	20%	15%	10%	10%
Power Switches	35%	30%	20%	15%	10%
CPU Utilization	75%	60%	50%	30%	20%
Memory					
SSR (Bulk storage)	30%	20%	20%	15%	10%
DRAM	75%	60%	50%	30%	20%
NVM (Flash)	75%	60%	50%	40%	30%
SFC EEPROM	75%	60%	50%	40%	30%
Avionics					
Serial Port Assignments	3	3	2	2	2
Bus Slot Assignments	3	2	2	1	1
Discrete I/O	30%	20%	15%	12.50%	10%
Analog I/O	30%	20%	15%	12.50%	10%
Earth to S/C Link(C)	3 db	3 db	3 db	3 db	3 db
Link Margin Bit Error Rate (3 sigma)	1.00E-06	1.00E-05	1.00E-05	1.00E-05	1.00E-05
Bus Bandwidth	60%	60%	55%	55%	50%
Mission Data Volume	20%	20%	15%	10%	10%
ASIC/FPGA Gates Remaining	40%	30%	20%	15%	10%
Crew IVA Time	40%	30%	20%	10%	10%



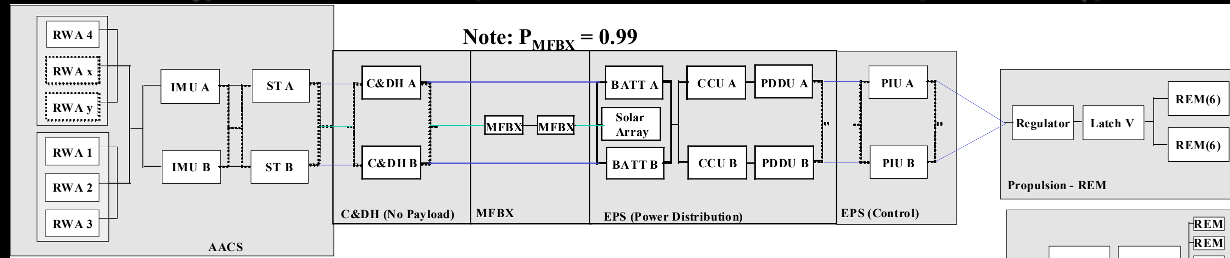
4. Everyone is not a systems engineer

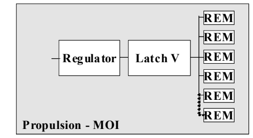






5. Why can't the system be calculated to a first-order on a white board? Why only by Sims and Monte Carlo's …





6. Mathematical reliability, really?

EPS/C&DH BLOCK :

$$P_{Thrust} = P_{AACS} * (1-(1-P_{SA} * (1-(1-P_{BATT})^2) * P_{CCU} * P_{PDDU} * P_{PIU} * P_{C\&DH})^2)* P_{REM}$$

$$P_{T\_MOI} = P_{AACS} * (1-(1-P_{SA} * (1-(1-P_{BATT})^2) * P_{CCU} * P_{PDDU} * P_{PIU} * P_{C\&DH})^2)* P_{MOI}$$

EPS/C&DH X-Strap :

$$P_{Thrust} = P_{AACS} * (1-(1-P_{SA} * (1-(1-P_{BATT})^2) * P_{CCU} * P_{PDDU} * P_{PIU})^2) * P^2_{MFBX} *(1-(1-P_{C\&DH})^2) * P_{REM}$$

$$P_{T\_MOI} = P_{AACS} * (1-(1-P_{SA} * (1-(1-P_{BATT})^2) * P_{CCU} * P_{PDDU} * P_{PIU})^2) * P^2_{MFBX} *(1-(1-P_{C\&DH})^2) * P_{MOI}$$

Common mode failure …

The simultaneous loss of 4 of 6 Russian module computers on ISS, in 2007 due to water condensation in a zero-g environment

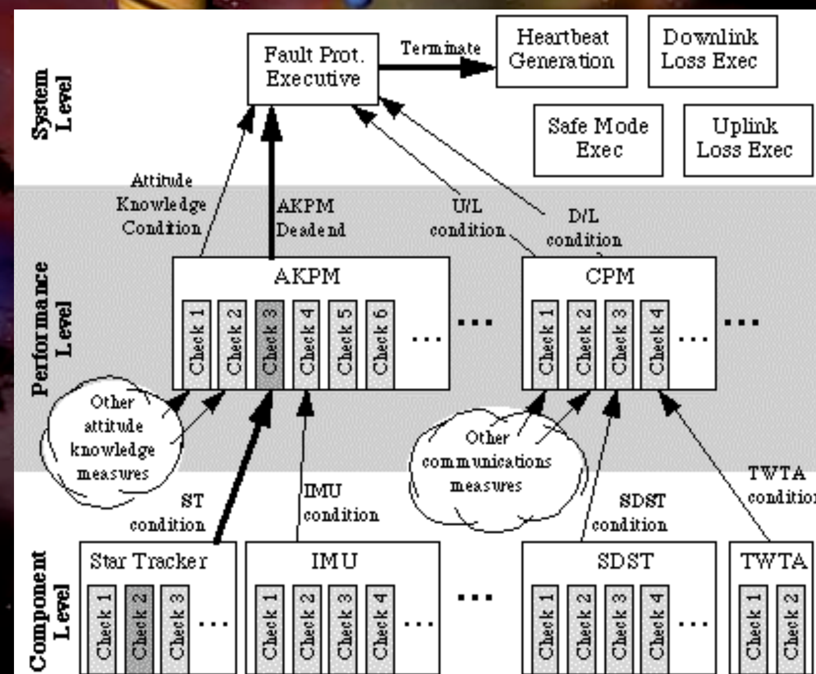
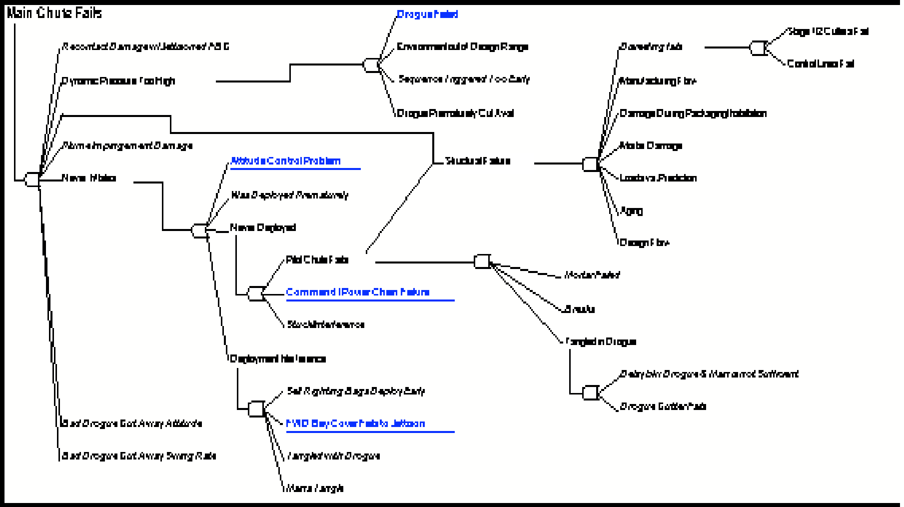


Image Credits: NASA



7. There are thousands of ways to fail … most have not been explored

8. Designing for earth-bound validation

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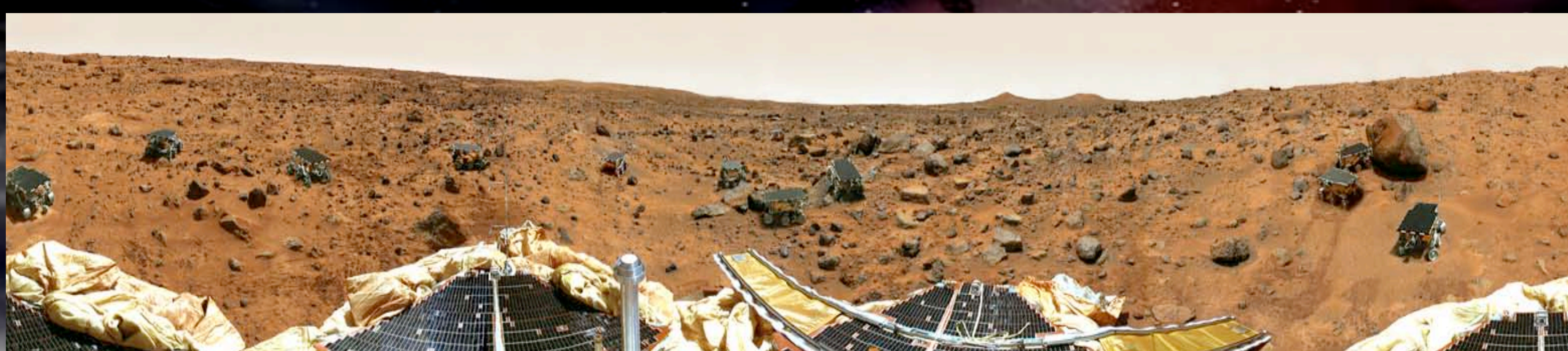
9. Success can spur us on to failure …



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10. Must not be paralyzed by fear of failure

Denali

SUCCESS!

FAILURE

FAILURE

Mars